Development of plant growth promoting bacteria-based consortium and its impact on *Triticum aestivum* L. grown under heavy metal stress

Synopsis

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Introduction

In today's growing world, there are various natural and anthropogenic activities that lead to the increase in heavy metal contamination in the environment. Industrialization as well as urbanisation directly affects this process. Heavy metals used extensively in industries like textile industries, leather industries, automobile factories, paper mills, coal mines, *etc*., are discharged in the nearby water and also deposited into the soil. Continuous irrigation in agriculture fields leads to the addition of these heavy metals to the crop, which ultimately accumulate in the food chain (Kumar et al., 2019).

Heavy metals are naturally present in the soil, but in trace amounts. Through various activities these heavy metals are deposited in the soil, become harmful and also distress humans, plants and the environment. Soil pollution is one of the concerns regarding the release of heavy metals. They deteriorate the upper layer of soil, which makes it harmful for crops, resulting in stress and low yield (Li et al., 2019).

The increasing level of heavy metals in plant species disturbs their metabolism and growth processes. Increasing concentrations of these heavy metals also affect soil pH and microbial diversity. Many plant species accumulate heavy metals in their different parts, which impairs their cell division, root elongation, growth, seed germination and other processes. Heavy metals also alter the confirmation of protein and DNA and inhibit their functions (Morales et al., 2016).

Around the world, wheat is a significant staple crop for agriculture. Wheat, like the majority of plants, is at the foundation of the food chain and takes up both indispensable and dispensable components from the soil (Ran et al., 2019). Global po). Takings are expected to surpass 10 billion by 2050, mandating increased food production, a challenge that nations will attempt to address (Saravi et al., 2016). Taking up 22% of all farmed areas, wheat constitutes one of the most significant crops (Shah et al., 2018) and provides 60% of the global population with their main source of food (Zhou et al., 2022). In the course of their lives, wheat plants are continually exposed to a variety of environmental challenges, and as a result, they have developed the ability to adjust to these stresses (Shafiq et al., 2019). Wheat plants have demonstrated a significant propensity to accumulate high concentrations of heavy metals, such as Cd, Pb, and Cu (Zhang et al., 2021; Wang et al., 2017).

Cells have strict regulations over their metal homeostasis. However, the breakdown of homeostasis

causes reactive oxygen species (ROS) to build up. Many methods, such as heat treatment, landfill disposal, excavation, and other are used to remove heavy metal contamination; however, these methods are more labour intensive and expensive (Abdelgawad et al., 2020). Microorganisms have developed various strategies for their survival in heavy metal-polluted habitats. These organisms are known to develop and adopt different detoxifying mechanisms such as biosorption, bioaccumulation, biotransformation and biomineralization, which can be exploited for bioremediation either *ex-situ* or *in-situ* (Dixit et al., 2015). Naturally occurring microbes can be used to prevent soil pollution as they can be used to reduce contaminants in the environment with the help of biological transformation.

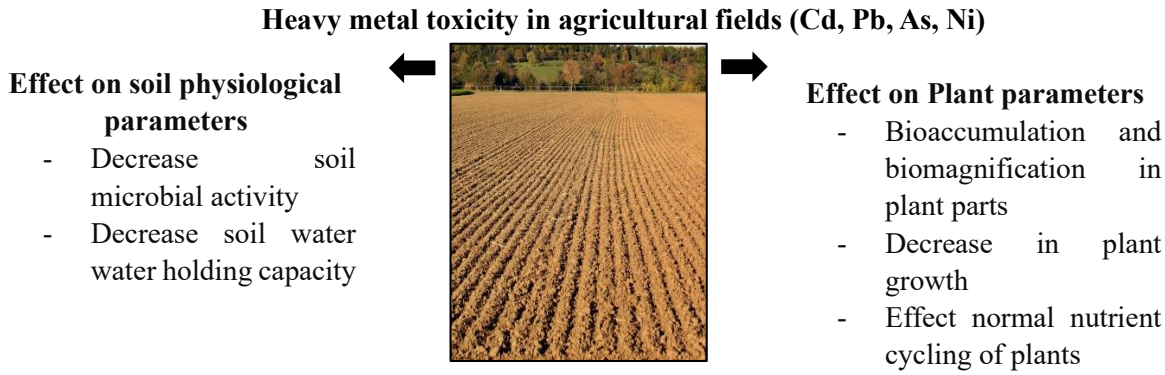
Heavy metal toxicity in agricultural fields (Cd, Pb, As, Ni)
Effect on soil physiological parameters
- Decrease soil microbial activity
- Decrease soil water water holding capacity
Effect on Plant parameters
- Bioaccumulation and biomagnification in plant parts
- Decrease in plant growth
- Effect normal nutrient cycling of plants

Fig 1: Negative effects of heavy metals on different parameters of soil and plant

Heavy metals are deposited in the soil or in the environment due to their non-biodegradable nature. Microorganisms can bioaccumulate or biosorp these heavy metals and convert them into non harmful substances. Keeping the above view in mind, the present study is proposed with the ultimate goal in the selection, identification, screening and development of the best suited consortium for the bioremediation of contaminated soil. It will promote agricultural sustainability and give access to the potential of microbes for the production of crops by mitigating the heavy metal problem in local soil.

Some advantageous aspects of the proposed study are as follows-

- The bare minimum amount needed for acquiring chemical additives and fertilizers.
- Enhances the soil quality by removing toxic compounds.
- Strengthening of the physical, chemical, and biological characteristics of soil as well as the promotion of soil-aggregate stability.
- The nutrients at lower depths become available to the plants as a result of an increase in biological activity.

- It functions to lessen the soil's evaporation-induced moisture loss.
- Environmental factors pertaining to the post-enhanced soil's capacity to store carbon.
- Make an effort to support "Swachh Bharat Abhiyan."

Objectives-

1) *In-vitro* screening and selection of heavy metal-resistant PGPB for their growth-promoting activities.
2) To study the efficacy of different selected strains of PGPB under various concentrations of heavy metal.
3) To develop the consortium with best-performing PGPB strains and to check its impact on seed germination and seedling attributes of *Triticum aestivum* L. under different heavy metal concentrations.
4) Effect of PGPB-based consortium on growth, physico-chemical parameters of *Triticum aestivum* L. grown under heavy metal stress.

Review of Literature

Systematic position of plant According to the system of classification of Arthur Cronquist (1981), *Triticum aestivum* L. occupies the following systematic position:

Table 1 Shows the Systemic classification of *Triticum aestivum* L.

Kingdom – Plantae
Division – Magnoliophyta
Class – Liliopsida
Order – Poales
Family – Poaceae
Genus – *Triticum*
Species – *aestivum* L.

Figure 2 represents image of *Triticum aestivum* L.
(Source: *https://pixahive.com/photo/wheat-plant-in-a-farm/*)

Description of Plant

Wheat (*Triticum aestivum* L.) is a staple grain and the second most widely grown cereal crop worldwide, following rice. One of the main grains in the diet, wheat has a big impact on both human health and the diet's nutritional value. Wheat stems are cylindrical and hollow. They have nodes (joints) where leaves are attached. Wheat leaves are long and narrow with parallel venation. They are arranged alternately along the stem. Wheat plants produce inflorescences known as spikes or ears. Each spike consists of several spikelets arranged alternately along the central axis. Spikelet's contain florets, which are small flowers.

Wheat florets are small and inconspicuous. Each floret consists of reproductive structures such as stamens (male) and pistils (female). Spikelets are the basic units of the wheat inflorescence. Each spikelet contains several florets arranged along a central axis. Wheat has a fibrous root system. Roots anchor the plant and absorb water and nutrients from the soil. The fruit of the wheat plant is a caryopsis, commonly referred to as a grain or wheat kernel. Wheat plants vary in height depending on the variety and environmental conditions. Height ranges from a few inches to several feet.

Sources of Heavy metals

There have been widespread reports of heavy metal contamination in India. Groundwater in about 718 districts has been contaminated by lead, cadmium, chromium, and arsenic (Mohan et al., 2018). According to (Dotaniya et al., 2015), Sites like Vadodara (Gujarat), Ranipet (Tamil Nadu), Talcher (Orissa), Ratlam (Madhya Pradesh), Ganjam (Orissa), Singrauli (Madhya Pradesh), Balai (Uttar Pradesh), and Malanjkhand (Madhya Pradesh) are heavily contaminated due to industrialization.

In general, soil at industrial sites can have distinct groups of heavy metal(loid) contaminants, which

depend on the respective industries and their raw materials and products. Soils in all urban areas are generally contaminated with lead (Pb), zinc (Zn), cadmium (Cd) and copper (Cu) from traffic, paint and many other non-specific urban sources (Alloway et al., 2013). Heavy metals are a serious threat to soil quality due to their persistence after entering the soil (McGrath et al., 1987). It has been demonstrated repeatedly that heavy metals adversely affect biological functions in soil. According to Jin et al., 2019, risk-based environmental management relies upon identifying pollution sources, pathways, and the exposed population. Heavy metals have high densities, different functional groups are present like thioether, hydroxyl group, phosphoryl and other by this are not easy to degrade and accumulate in environment. According to the study conducted by Rizvi et al., 2020, the distribution of heavy metals in soil is controlled by: (i) precipitation and dissolution, (ii) ion exchange, adsorption and desorption, (iii) aqueous complexation, (iv) biological immobilization and mobilization, and (v) plant uptake. Based on these properties, soil metals have been grouped into five key geochemical categories: (i) exchangeable, (ii) metal bound to carbonate phase, (iii) metal attached to Fe and Mn oxides, (iv) bound to organic matter, and (v) residual metal.

Role of different plant growth-promoting bacterial strains in the removal of heavy metals -

Microorganism plays an essential part in bioremediation of heavy metals. By using genetic engineering, genetically modified organisms can be generated which can likely reduce different types of polycyclichydrocarbons (PAHs). *Flavobacterium, Pseudomonas, Bacillus*, *Arthrobacter, Corynebacterium, Methosinus, Rhodococcus, Mycobacterium, Stereum hirsutum, Nocardia, Methanogens, Aspergilus niger, Pleurotus ostreatus, Rhizopus arrhizus, Azotobacter, Alcaligenes, Phormidium valderianum, Ganoderma applantum* are some microbial species that help in bioremediation of heavy metals (Verma et al., 2019). The following table represents different bacterial strains in heavy metal removal –

Table 2: Different bacterial strains in heavy metal removal

Bacterial strains	**Heavy metal**	**Process of heavy metal removal**	**References**
Bacillus sp. PZ 1	Pb	Bioaccumulation	Ren et al., 2015
Arthrobacter viscosus	Pb	Bioaccumulation	Pham et al., 2022
Pseudomonas aeruginosa RW9	Cr	Bioaccumulation	Mat Arisha et al., 2021
Bacillus sp. Q5	Cd	Bioaccumulation	Heidari et al., 2020
Bacillus megaterium sp.	Pb	Bioaccumulation	Yohanna et al., 2018

Enterobacter cloacae	Cd	Bioaccumulation	Ghosh et al., 2022
Rhizopus stolonifer	Pb, Ni	Bioaccumulation	Njoku et al., 2020
Alcaligenes sp. MMA	Cr, Zn, Cd	Bioaccumulation	Sodhi et al., 2020
Streptomyces sp. K11	Zn	Bioaccumulation	Sedlakova et al., 2019
Pseudomonas sp.	Pb, Cd	Bioaccumulation	Abatenh et al., 2017
Pseudomonas alcaliphila NEWG-2	Cr	Biosorption	El-Nagger et al., 2020
Cellulosimicrobium funkei AR6	Cr	Biosorption	Karthik et al., 2017
Acinetobacter sp. WB-2	Cr	Biosorption	Jin et al., 2017
Klebsiella penumoniae	Cd	Biosorption	Khan et al., 2015
Pseudomonas aeruginosa	Cd,Pb	Biosorption	Karimpour et al., 2018
Staphylococcus epidermidis	Cr, Zn	Biosorption	Quiton et al., 2017
Methylobacterium sp.	Pb	Biosorption	Photolo et al., 2021
Arthrobacter sp. 25	Pb	Biosorption	Jin et al., 2016
Micrococcus luteus DE2008	Pb,Cu	Biosorption	Puven et al., 2012

Soil pollution is one the concern where urgent action and techniques required because it causing harm to the food chain and also to the ecological entities. Mainly contaminated water by irrigation and some chemical fertilizers used by farmers triggering soil contamination which affects human health as well as crop production in agricultural fields situated near the industrial area. Sites contaminated with hazardous materials are a common and urgent problem across the world.

Bacterial consortium

As we know, microorganisms found in the environment or in soil, in complexes with other substances. Pure cultures of microbes are widely used in the degradation of heavy metals, show good efficiency and minimizes the toxicity of metals. Individual microorganisms can metabolize only a limited range of hydrocarbon substrates, so assemblages of mixed populations with overall broad enzymatic capacities are required to bring the rate and extent of petroleum biodegradation further (Perpetuo, et al., 2011). Several selenate-respiring bacterial species *Thauera selenatis*, *Sulfurospirillum barnesii*, and *Bacillus arseniciselenatis* have been well characterized and shown to respire anaerobically by using SeO_4 as the terminal electron 137 acceptor (Ghazali et al., 2004). *Bacillus circulans* strain EB1, a heavy-metalresistant bacterium, has been reported to remove manganese, zinc, copper, nickel and cobalt during its active growth cycle, number of chromium reducing bacteria including *Pseudomonas*, *Escherichia* and *Bacillus*, *Desulfovibrio*, *Desulfomicrobium* and *Desulfotomaculum*, *Shewanella alga* and

Pyrobaculum islandicum have been studied till date (Eswayah et al.,2016). The study by Asri, et al., (2023) investigated four bacteria, *Bacillus sp.*, *Bacillus cereus*, *Enterococcus fecium,* and *Enterococcus mundtii* to mitigate heavy metal stress. (Asri et al., 2023). Biosorptive capacity for Pb(II), Cd(II) and Cu(II) decreased with an increase of metal concentration, reaching 142, 43.5 and 36.2 mg/g at initial concentration of 300 mg/l, respectively (Iyer et al., 2005). The speciation, behaviour, transport, and decisive fate of heavy metals in instinctive ecosystems depends mainly on the sorption with surface functional groups of microbial communities. Different types of biomass were capable of efficiently accumulating heavy metal ions (Özdemir et al., 2013; Oves et al., 2013).

Materials & Methods

For objective 1:

- Procurement of Selected strains from authentic source (MTCC or ATCC)
- Selected bacterial strains will be assessed for their plant growth promoting activity are as follows:
- Ammonia production (The Cappuccino and Sherman et al., 1992)
- Phosphate solubilization (Jasim et al., 2013)
- Potassium solubilization (Sugumaran and Janartham et al., 2007)
- IAA production (colorimetric assay using Ehmann's et al., 1977)
- Siderophore production (Schwyn and Neilands et al., 1987)

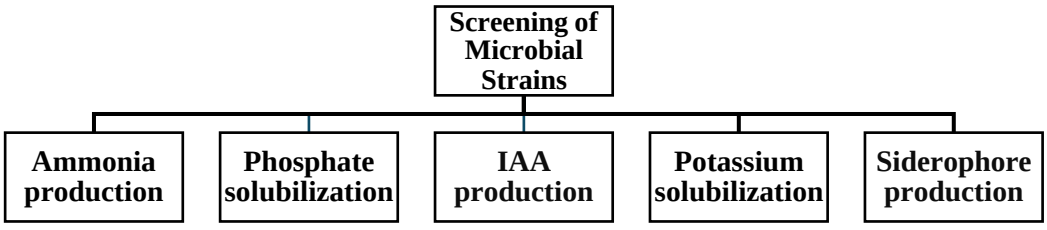

Fig 2: Different screening parameters for the selection of potent bacterial strains

For objective 2:

Selected microbial strains will be further assessed for their heavy metal resistant capacity. They will be inoculated into the broth containing different concentrations of heavy metals and will be monitored at various time intervals. After incubation at different time intervals, Samples will be taken periodically

for the analysis of viability by taking optical density at 600nm.

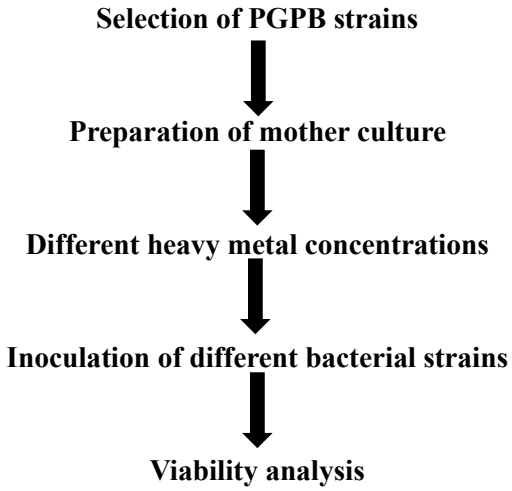

Fig 3: Above flow charts showing the steps that will be taken for the assessment of the efficacy of selected bacterial strains against heavy metals

For objective 3:

After the assessment of heavy metal resistant by PGPB strain, they will be further analysed for compatibility with other selected strains for the development of consortium. Heavy metal with different concentrations will be used. Evaluation will be done at different time intervals to understand the accurate results of their compatibility with other strains. Best developed compatible consortium will be selected for further study. Based on consortium efficiency with reference to heavy metal removal they will be selected for pot experiments as shown in figure below-

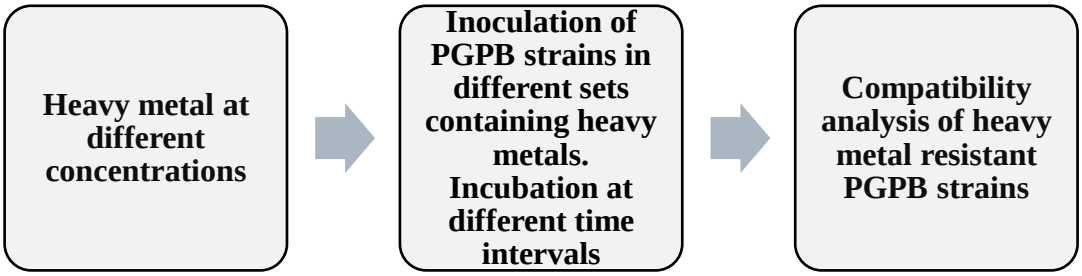
Heavy metal at different concentrations
Inoculation of PGPB strains in different sets containing heavy metals. Incubation at different time intervals
Compatibility analysis of heavy metal resistant PGPB strains

Fig 4: Flow chart showing simple steps for compatibility analysis

To check the impact of developed consortium on seed germination and seedling attributes of *Triticum aestivum* L. under different heavy metal concentrations, following parameters will be determined:

i. Germination potential (GP)

ii. Germination rate (GR)

iii. Mean germination time (GT)

iv. Germination index (GI)

v. Seed vigour index

-Data will be recorded at regular interval of 3 days of sowing (DAS).

For objective 4:

After the selection of suited consortium based on their heavy metal resistant efficacy, pot experiments will be conducted. For the pot experiments, soil sample will be collected from Dayalbagh, Agra. The estimation of different plant parts for their growth activity will be analysed.

The estimation of the following parameters will be done:

A) Growth parameters:

Shoot length (cm)

Root length (cm)

Root fresh weight (gm)

Shoot fresh weight (gm)

Root dry weight (gm)

Shoot dry weight (gm)

B) Physiological and biochemical parameters:

- Total chlorophyll content (Lichtenthaler et al., 2001).
- Total carotenoid content (Lichtenthaler et al., 2001)
- NDVI (Greenseeker meter)
- Leaf area (L1-300C leaf area meter)
- Stomatal conductance (L1-600 fluoremeter)
- Chlorophyll a fluorescence (L1-600 fluoremeter)
- Lipid peroxidation (Health and packer et al., 1968)
- Hydrogen peroxide (Velikova et al., 2000)
- Proline content (Bates et al., 1973)
- Total antioxidant assay (Aebi et al., 1984)
- Heavy metal assessment (AAS/ICPMS)

- Statistical analysis of recorded data will be done by statistical software.

Significance of the study

This study will provide better understanding to the interactions of PGPB with heavy metals. **It will provide a research base to study further about the cytotoxicity of studied bacterial species in near future**. Various heavy metal removal bacterial species are found in nature but their efficiency could be increased by inoculating different strain with different capabilities. By this hypothesis, good results can be achieved.

Soil pollution is increasing day by day and through this, **we can better understand the process of bioremediation, heavy metal interaction with microorganisms and emerging new concepts**. Many microbial consortia are now used as biofertilizer and found to promote the plant growth and also have positive effects on soil. From this study, **best suited microbial consortium can be developed and further checked for its efficacy in removing heavy metals as eco-friendly approach. From the future perspective, using selected microbial consortium, we can also enhance the nitrogen fixing capacity of PGPB, by maintaining different conditions**.

Mixed culture can also improve productivity. **They can also be used as plant bio stimulant, provide resistant against osmotic stress, salinity stress, nutrient deficiency stress, heat stress, generate more phytohormones**, etc.

From the agriculture point of view, it is important to know about the biological activities and changes occur during interaction with toxic compounds. In future best suited consortia can be used by mixing it with manures, industrial waste and vermicompost to improve their performance. It will be benefited from the ecological point of view and can contribute to the "Swach Bharat Abhiyan"

References

Abatenh, E., Gizaw, B., Tsegaye, Z., &Wassie, M. (2017). The role of microorganisms in bioremediation-A review. *Open Journal of Environmental Biology*, *2*(1), 038-046.

AbdElgawad, H., Zinta, G., Hamed, B.A., Selim, S., Beemster, G., Hozzein, W.N., Wadaan, M.A., Asard, H. and Abuelsoud, W. (2020). Maize roots and shoots show distinct profiles of oxidative stress and antioxidant defense under heavy metal toxicity. *Environmental Pollution*, *258*, p.113705.

Aebi, H. (1984). Catalase in vitro. In *Methods in enzymology*, *105*, 121-126.

Alloway, B.J. (2013). Sources of heavy metals and metalloids in soils. In *Heavy Metals in Soils* (pp. 11-50). Springer, Dordrecht.

Ahmed, A., Randhawa, M. A., &Sajid, M. W. (2014). Bioavailability of calcium, iron, and zinc in whole wheat flour. In *Wheat and Rice in Disease Prevention and Health* (pp. 67-80). Academic Press.

Asri, M., Ouafi, R., Bahafid, W., Elabed, S., Koraichi, S. I., Costa, F., ... & El Ghachtouli, N. (2023). Chromium removal by newly developed microbial consortia supported on wood husk. *Desalination and Water Treatment*, *289*, 80-91.

Bates, L. S., Waldren, R.P., &Teare, I.D. (1973). Rapid determination of free proline for water-stress studies. *Plant and Soil, 39*, 205-207.

Cappuccino, J. G., & Sherman, N. (1992). Biochemical activities of microorganisms. *Microbiology, A Laboratory Manual. The Benjamin/Cummings Publishing Co. California, USA*, 188-247.

Dixit, R., Malaviya, D., Pandiyan, K., Singh, U.B., Sahu, A., Shukla, R., Singh, B.P., Rai, J.P., Sharma, P.K., Lade, H. and Paul, D. (2015). Bioremediation of heavy metals from soil and aquatic environment: an overview of principles and criteria of fundamental processes. *Sustainability*, *7*(2), pp.2189-2212.

Eswayah, A.S., Smith, T.J. and Gardiner, P.H. (2016). Microbial transformations of selenium species of relevance to bioremediation. *Applied and Environmental Microbiology*, *82*(16), pp.4848-4859.

El-Naggar, N. E. A., El-Khateeb, A. Y., Ghoniem, A. A., El-Hersh, M. S., &Saber, W. I. (2020). Innovative low-cost biosorption process of Cr6+ by *Pseudomonas alcaliphila*NEWG-2. *Scientific Reports*, *10*(1), 14043.

Ehmann, A. (1977). The Van Urk-Salkowski reagent—a sensitive and specific chromogenic reagent for silica gel thin-layer chromatographic detection and identification of indole derivatives. *Journal of chromatography A, 132*(2), 267-276.

Ghosh, A., Pramanik, K., Bhattacharya, S., Mondal, S., Ghosh, S. K., & Maiti, T. K. (2022). A potent cadmium bioaccumulating *Enterobacter cloacae* strain displays phytobeneficial property in Cdexposed rice seedlings. *Current Research in Microbial Sciences*, *3*, 100101.

Ghazali, F.M., Rahman, R.N.Z.A., Salleh, A.B. and Basri, M. (2004). Biodegradation of hydrocarbons

in soil by microbial consortium. *International Biodeterioration& Biodegradation*, *54*(1), pp.61-67.

Heidari, P., &Panico, A. (2020). Sorption mechanism and optimization study for the bioremediation of Pb (II) and Cd (II) contamination by two novel isolated strains Q3 and Q5 of *Bacillus sp*. *International Journal of Environmental Research and Public Health*, *17*(11), 4059.

Heath, R. L., & Packer, L. (1968). Photo peroxidation in isolated chloroplasts. *Archives of biochemistry and biophysics, 125*(1)*, 189–198.*

Iyer, A., Mody, K. and Jha, B. (2005). Biosorption of heavy metals by a marine bacterium. *Marine Pollution Bulletin*, *50*(3), pp.340-343.

Jin, Y., O'Connor, D., Ok, Y.S., Tsang, D.C., Liu, A. and Hou, D. (2019). Assessment of sources of heavy metals in soil and dust at children's playgrounds in Beijing using GIS and multivariate statistical analysis. *Environment International*, *124*, pp.320-328.

Jasim, B., Jimtha, C. J., Jyothis, M., & Radhakrishnan, E. K. (2013). Plant growth promoting potential of endophytic bacteria isolated from Piper nigrum. *Plant growth regulation, 71*(1), 1-11.

Jin, Y., Wang, X., Zang, T., Hu, Y., Hu, X., Ren, G., ... & Qu, J. (2016). Biosorption of lead (II) by *Arthrobacter sp*. 25: process optimization and mechanism. *Journal of Microbiology and Biotechnology*, *26*(8), 1428-1438.

Jin, R., Wang, B., Liu, G., Wang, Y., Zhou, J., & Wang, J. (2017). Bioreduction of Cr (VI) by *Acinetobacter sp*. WB-1 during simultaneous nitrification/denitrification process. *Journal of Chemical Technology & Biotechnology*, *92*(3), 649-656.

Karthik, C., Ramkumar, V. S., Pugazhendhi, A., Gopalakrishnan, K., &Arulselvi, P. I. (2017). Biosorption and biotransformation of Cr (VI) by novel *Cellulosimicrobiumfunkei* strain AR6. *Journal of the Taiwan Institute of Chemical Engineers*, *70*, 282-290.

Khan, Z., Hussain, S. Z., Rehman, A., Zulfiqar, S., &Shakoori, A. R. (2015). Evaluation of cadmium resistant bacterium, *Klebsiellapneumoniae*, isolated from industrial wastewater for its potential use to bioremediate environmental cadmium. *Pakistan Journal of Zoology*, *47*(6).

Karimpour, M., Ashrafi, S. D., Taghavi, K., Mojtahedi, A., Roohbakhsh, E., &Naghipour, D. (2018). Adsorption of cadmium and lead onto live and dead cell mass of *Pseudomonas aeruginosa*: A

dataset. *Data in Brief*, *18*, 1185-1192.

Kumar, S., Prasad, S., Yadav, K. K., Shrivastava, M., Gupta, N., Nagar, S., ... &Malav, L. C. (2019). Hazardous heavy metals contamination of vegetables and food chain: Role of sustainable remediation approaches-A review. Environmental research, 179, 108792.

Li, C., Zhou, K., Qin, W., Tian, C., Qi, M., Yan, X., & Han, W. (2019). A review on heavy metals contamination in soil: effects, sources, and remediation techniques. Soil and Sediment Contamination: An International Journal, 28(4), 380-394.

Lichtenthaler, H. K., &Buschmann, C. (2001). Extraction of photosynthetic tissues: chlorophylls and carotenoids. *Current protocols in food analytical chemistry*, *1*(1), F4-2.

Mat Arisah, F., Amir, A. F., Ramli, N., Ariffin, H., Maeda, T., Hassan, M. A., & Mohd Yusoff, M. Z. (2021). Bacterial Resistance against heavy metals in *Pseudomonas aeruginosa* RW9 involving hexavalent chromium removal. *Sustainability*, *13*(17), 9797.

Mohan,V. (2018). Across India, high levels of toxins in groundwater. The Times of India. Details available at https://timesofindia.indiatimes.com/india/govt-body-finds-high-levels-of-groundwater- contamination-across-india/articleshow/65204273.cms, last accessed on 2 June, 2019

Morales, M. E., Derbes, R. S., Ade, C. M., Ortego, J. C., Stark, J., Deininger, P. L., & Roy-Engel, A. M. (2016). Heavy metal exposure influences double strand break DNA repair outcomes. PloS one, 11(3), e0151367.

Njoku, K. L., Akinyede, O. R., &Obidi, O. F. (2020). Microbial remediation of heavy metals contaminated media by *Bacillus megaterium* and *Rhizopusstolonifer*. *Scientific African*, *10*, e00545.

Oves, M., Khan, M.S. and Zaidi, A. (2013). Biosorption of heavy metals by *Bacillus thuringiensis* strain OSM29 originating from industrial effluent contaminated north Indian soil. *Saudi Journal of Biological Sciences*, *20*(2), pp.121129.

Özdemir, S., Kılınç, E., Poli, A. and Nicolaus, B. (2013). Biosorption of heavy metals (Cd2+, Cu2+, Co2+, and Mn2+) by thermophilic bacteria, *Geobacillusthermantarcticus*

and *Anoxybacillusamylolyticus*: equilibrium and kinetic studies. *Bioremediation Journal*, *17*(2), pp.86-96

Pham, V. H. T., Kim, J., Chang, S., & Chung, W. (2022). Bacterial biosorbents, an efficient heavy metals green clean-up strategy: prospects, challenges, and opportunities. *Microorganisms*, *10*(3), 610.

Photolo, M. M., Sitole, L., Mavumengwana, V., &Tlou, M. G. (2021). Genomic and physiological investigation of heavy metal resistance from plant endophytic *Methylobacteriumradiotolerans* MAMP

4754, isolated from Combretumerythrophyllum. *International Journal of Environmental Research and Public Health*, *18*(3), 997.

Puyen, Z. M., Villagrasa, E., Maldonado, J., Diestra, E., Esteve, I., &Solé, A. (2012). Biosorption of lead and copper by heavy-metal tolerant *Micrococcus luteus* DE2008. *Bioresource Technology*, *126*, 233-237.

Perpetuo, E.A., Souza, C.B. and Nascimento, C.A.O. (2011). Engineering bacteria for bioremediation. *Progress in Molecular and Environmental Bioengineering-From Analysis and Modeling to Technology Applications*.

Quiton, K. G., Doma Jr, B., Futalan, C. M., & Wan, M. W. (2018). Removal of chromium (VI) and zinc (II) from aqueous solution using kaolin-supported bacterial biofilms of Gram-negative *E. coli* and Gram-positive *Staphylococcus epidermidis*. *Sustainable Environment Research*, *28*(5), 206-213.

Ran, J., Wang, D., Wang, C., Zhang, G., & Zhang, H. (2016). Heavy metal contents, distribution, and prediction in a regional soil–wheat system. *Science of the Total Environment*, *544*, 422-431.

Rajendiran, S., Dotaniya, M. L., Coumar, M. V., Panwar, N. R., & Saha, J. K. (2015). Heavy metal polluted soils in India: status and countermeasures. *JNKVV Res J*, *49*(3), 320-337.

Ren, G., Jin, Y., Zhang, C., Gu, H., & Qu, J. (2015). Characteristics of *Bacillus sp.* PZ-1 and its biosorption to Pb (II). *Ecotoxicology and Environmental Safety*, *117*, 141-148.

Rizvi, A., Zaidi, A., Ameen, F., Ahmed, B., AlKahtani, M.D. and Khan, M.S. (2020). Heavy metal induced stress on wheat: phytotoxicity and microbiological management. *RSC Advances*, *10*(63), pp.38379-38403.

Sedlakova-Kadukova, J., Kopcakova, A., Gresakova, L., Godany, A., &Pristas, P. (2019).

Bioaccumulation and biosorption of zinc by a novel *Streptomyces* K11 strain isolated from highly alkaline aluminium brown mud disposal site. *Ecotoxicology and Environmental Safety*, *167*, 204-211.

Saravi, S. S. S., &Dehpour, A. R. (2016). Potential role of organochlorine pesticides in the pathogenesis of neurodevelopmental, neurodegenerative, and neurobehavioral disorders: A review. *Life Sciences*, *145*, 255-264.

Schwyn, B., &Neilands, J. B. (1987). Universal chemical assay for the detection and determination of siderophores. *Analytical Biochemistry*, *160*(1), 47-56.

Shah, T., Xu, J., Zou, X., Cheng, Y., Nasir, M., & Zhang, X. (2018). Omics approaches for engineering wheat production under abiotic stresses. *International Journal of Molecular Sciences*, *19*(8), 2390.

Shafiq, S., Zeb, Q., Ali, A., Sajjad, Y., Nazir, R., Widemann, E., & Liu, L. (2019). Lead, cadmium and zinc phytotoxicity alter DNA methylation levels to confer heavy metal tolerance in wheat. *International Journal of Molecular Sciences*, *20*(19), 4676.

Sodhi, K. K., Kumar, M., & Singh, D. K. (2020). Multi-metal resistance and potential of Alcaligenes sp. MMA for the removal of heavy metals. *SN Applied Sciences*, *2*, 1-13.

Sugumaran P &Janartham B (2007). Solubilization of potassium minerals by bacteria and their effect on plant growth. *World journal of agricultural sciences 3*(3) 350-355.

Verma, S. and Kuila, A. (2019). Bioremediation of heavy metals by microbial process. *Environmental Technology & Innovation*, *14*, p.100369.

Velikova, V., Yordanov, I., &Edreva, A. J. P. S. (2000). Oxidative stress and some antioxidant systems in acid rain-treated bean plants: protective role of exogenous polyamines. *Plant science*, *151*(1), 59-66.

Wang, S., Wu, W., Liu, F., Liao, R., & Hu, Y. (2017). Accumulation of heavy metals in soil-crop systems: a review for wheat and corn. *Environmental Science and Pollution Research*, *24*, 1520915225.

Wheat plant in a farm - PixaHive. (2024). PixaHive. *https://pixahive.com/photo/wheat-plant-in-a-farm/*

Yohanna, A. R., Abioye, O., Mohammed, M., &Salawu, Y. (2018). Biosorption of lead and arsenic using *Bacillus lacus*ak 74 and *Herbaspirillium aquaticum* 4430 isolates from jebba lake–nigeria. in 37

th *Annual Conference* (p. 272).

Zhang, D., Zhou, H., Shao, L., Wang, H., Zhang, Y., Zhu, T., ... & Ma, L. (2022). Root characteristics critical for cadmium tolerance and reduced accumulation in wheat (*Triticumaestivum* L.). *Journal of Environmental Management*, *305*, 114365.

Zhou, M., & Li, Z. (2022). Recent advances in minimizing cadmium accumulation in wheat. *Toxics*, *10*(4), 187.